Incised Grids: Enhancing the Readability of Tangible Graphs for the Blind

by

John L. Barth

American Printing House for the Blind

1983

Louisville, Kentucky

Incised Grids: Enhancing the Readability of Tangible Graphs for the Blind

John L. Barth

American Printing House for the Blind

Louisville, Kentucky

Abstract

The transformation of a graphic display into tangible form for blind persons is usually achieved by raising the entire image above the surface. In the case of tangible line graphs, this format causes readability problems by degrading figure (data curve)-ground (grid) differentiation. This study assessed the feasibility of a new design format involving both raised and incised elements in the same display. The results from 24 blind students in grades 4-7 indicated that an incised grid-raised data curve format significantly improves graph reading performance relative to a raised grid-raised data curve format. The importance of designing displays in ways which are compatible with the perceptual-motor capabilities of blind persons is discussed.

Running Head: Tangible Graphs

Keywords: graphs, graphics, blind, tactual

Incised Grids: Enhancing the Readability Of Tangible Graphs for the Blind

Graphic displays in the form of maps, graphs, diagrams, and charts represent an indispensable medium for the communication of information and, consequently, have proliferated to an extent unparalleled in history. It is highly probably that the percentage of such nonverbal materials will continue to increase in the forseeable future (Kirchner, 1979). Quite simply, graphic materials have been recognized as having the capability of conveying certain types of information that cannot be easily or efficiently represented in verbal form. For example, the spatial relationships of the components of a map, the schematic representation of objects in diagrams, or the relationships between variables in a graph do not lend themselves readily to verbal description. Any person, regardless of visual status, is placed at a disadvantage if not provided access to the wealth of information available in graphic displays. Recognition of this fact in the field of the blind has led to increased efforts in the last two decades to convert visual graphics into tangible form. This has resulted in the investigation of a number of concerns, including methods of production (Barth, 1982; Gill, 1973; James, 1975; Wiedel & Groves, 1969), symbology and display design (Bentzen & Peck, 1979; Berla' & Murr, 1975a; Nolan & Morris, 1971; Schiff, Kaufer, & Mosak, 1966), and reading and interpretation (Berla', 1981; Berla' & Butterfield, 1977a; Berla', Butterfield, & Murr, 1976; James & Armstrong, 1975).

Both visual and tangible graphic displays convey information by means of three types of symbology. Areal symbols are needed to differentiate regions of extent; point symbols to identify specific locations, landmarks, or objects; and linear symbols to represent boundaries or to connect points. All three types are frequently required on a single display to represent the pertinent information. Unfortunately, the use of all three types of symbols in a tangible display can sometimes degrade the efficiency of reading and interpreting that display. It is well known in visual and auditory research as well as vibrotactile research (Geldard, 1972) that irrelevant information can impair reception of significant informational signals. Similarly, in research concerned with tangible displays, areal patterns or textures have been found to act as noise in the tactual communication channel, decreasing the efficiency of perceptual-motor tasks involving point and linear symbols. In a study by Berla' and Murr (1975b), the addition of textured areal symbols to a tangible political pseudomap decreased blind students' accuracy of locating target point symbols by 20% and increased location time by 36%. Furthermore, the time needed to track a raised line increased by 41% when the textures were present.

There are probably several factors operating to produce these effects. For example, as Berla' and Murr have hypothesized, there is a certain degree of superfluous stimulation generated as the fingertips search for target point symbols across a display containing texture, making it less likely for a student to detect a change in stimulation which signals the presence of a point symbol. Moreover, the intensity and frequency of the vibratory

stimulation are in part dependent on the speed of the fingertips as they move across a display. Reducing the speed of the scanning hand attenuates the effects of this added noise, but at the same time results in an increase in total task time.

When tracking a raised line with the fingertips, the surface area of the skin of the fingertip extends beyond the boundaries of the line and can thus make contact with textures located in close proximity to the line. It is conceivable that this additional tactual stimulation or noise represents a source of distraction to the subject. Again, by decreasing speed of movement, the extraneous stimulation can be somewhat attenuated, but at the cost of increasing the time needed to complete the task. Finally, whenever the fingertip departs from the line and enters a textured area, a decision has to be made as to whether or not the elements being felt are part of the line. Each such decision results in an increment in the time needed to complete the line-tracking task. Whatever the underlying cause or causes may be, it is evident that textures have a disruptive effect on the readability of tangible displays.

Line graphs, because of their widespread use, may represent an important instance of this type of display, with lines representing data curves being displayed against a background grid (Cartesian coordinate reference system). The task of tracking a data curve embedded in a grid might be analogous to the situation involving a line embedded in an areal pattern. If so, impaired trackability would be expected. This result was, in fact, obtained in a study by Barth (1983). In that experiment, four different types of raised

lines (wide interrupted, narrow interrupted, wide solid, narrow solid) were individually displayed both against a smooth background and a background of raised (thin solid) grid lines. The subjects were required to track the lines with their fingertips as quickly as possible under the two conditions. An adverse effect of the grid background on line-tracking performance was found. On the average it took students 144% longer to trace a line embedded in the areal pattern composed of crisscrossing grid lines than through the smooth background. This occurred despite the fact that all of the tracked lines were highly discriminable tactually from the grid line, despite the fact that the tracked lines were separated from the grid lines by a distance of 3 mm, and despite the fact that the lines composing the grid were only half as high as the lines embedded in them. The presence of background grid in a tangible line graph obviously adds tactuel noise that cannot be entirely filtered out when tracking a line embedded in it.

Based on this evidence, one might conclude that grids should be excluded from tangible line graphs. This would be a valid conclusion if the tracking of a data curve to determine its general shape and trend was the only important operation performed on graphs. It is not. Another is point location, the precise determination of the coordinate values associated with the points on the data curve. It is this operation which necessitates the employment of a coordinate reference system of tangible grid lines. Such a system facilitates the task of accurately identifying the point by point relationships between the two variables under consideration in a particular graph.

Recognizing that raised grids are (a) disruptive to line tracking performance and (b) useful in the precise determination of coordinate values of points located in the graph space, it is clear that the current method of graph representation in tangible form needs to be modified. A feasible solution to this problem may lie in a redesigning of graphs in a way that will enhance the tactual contrast between the figure (the data curve) and the ground (the grid). At present, both the figure and the ground are raised above the surface. A better design might involve the use of both raised and incised lines. By employing raised lines for the data curves and incised lines for the grid backgrounds, the problem of disruptive tactual stimulation may be eliminated or at least attenuated while at the same time preserving the benefits incurred by the inclusion of a grid background.

Normally, incised lines are not recommended for use in a tangible graphic display. Nolan (1971) found that the time needed to track shapes was significantly increased when lines were incised rather than raised. A similar result was obtained by Berla' and Butterfield (1977b) in a study involving the location of shapes in a tangible political pseudomap. However, graphs represent an instance where the benefits resulting from their use might outweight the deficits. The reduction in tracking speed associated with the incised lines might be amply compensated for by the increase in figure-ground differentiation. Besides, the use of incised lines for the grid in a tangible graph may not even result in this temporal deficit. Grid lines only run horizontally or vertically on a page and are always straight. These characteristics reduce the unpredictability of their excursions across the display. This reduction in uncertainty should result in a much easier tracking task than that required by Nolan or Berla' and Butterfield.

The purpose of the present study was to determine the effects of raised and incised grid backgrounds on typical perceptual-motor tasks required in tangible graph interpretation. These tasks included line tracking, location of minimum and maximum data curve points, location of point symbols, and the determination of the coordinate values associated with a graph point. It was expected that an incised grid format would facilitate graph reading performance relative to that achieved with a raised grid format.

Method

Subjects

The participants in this study were 24 totally blind students in grades 4-7. Their primary mode of reading was braille. They had no physical handicaps other than impaired vision. The average age of the students was 12.2 years (*SD* = 1.6). Half were male, half female.

Materials

All of the displays were embossed in paper, a medium which, despite its predominant use in the mass production of tangible graphics, has received little attention from researchers in the field. The method of display production involved (a) the embossing of the desired display in a folded zinc plate, .25 mm in thickness, to produce a male-female die set, and (b) the impressing of the display in heavy braille paper, .15 mm in thickness, by sandwiching the paper between the zinc plates and applying pressure with a mechanical platen press.

The four experimental tasks necessitated the construction of four sets of displays, each involving different design characteristics. The displays are shown in Figure 1. Each set will be described in turn.

Insert Figure 1 about here

Task A (line tracking). Three line patterns, differing in spatial configuration but not complexity, were individually displayed against each of the test backgrounds (raised grid, incised grid, no grid or control). In order to be reasonably assured that all three configurations (which resembled complex data curves) were equivalent in complexity, several design criteria were adhered to in their construction. All three patterns thus shared the following characteristics:

1. Four upward turns at junction points (a junction point being the place at which the direction of a line changes)
2. Four downward turns at junction points
3. An approximately equal distance in line length extending away from the body and toward the body
4. Two horizontal lines (25 mm and 50 mm)
5. A total line length of 50 cm

The raised line used for all of these patterns was a dotted line (line height: .50 mm; line width: 2 mm; dot center to dot center: 4 mm). The raised grid was composed of solid lines (line height: .25 mm; line width: 1.7 mm; grid grain: 12.7 mm). The incised grid was composed of the same solid lines as those used in the raised grid, but was embossed on the back of the displays. Data curves and grid lines were separated by a distance of 3 mm. X and y coordinate axes, 25.4 cm in length, were composed of a wide solid line (line width: 3.5 mm; line height: .5 mm).

Task B (location of minimum and maximum points). The displays for this task also involved three distinct line patterns. Each was again displayed against the three test backgrounds. The distinguishing characteristic among these three patterns was the display location of the highest and lowest excursions of the line patter: pattern 1--highest peak, right of center, and lowest peak, left of center; pattern 2--highest peak, left of center, and lowest peak, center; pattern 3--highest peak, center, and lowest peak, right of center. All three line patterns shared several characteristics in common:

1. A total line length of 31.0 cm.
2. Two high peaks separated by a vertical distance of 25.4 mm.
3. Two low peaks separated by a vertical distance of 25.4 mm.
4. A vertical distance of 88.9 mm between the highest and lowest peaks.

The raised and incised lines used to represent the data curves, axes, and grid backgrounds were the same as those described for Task A.

Task C (location of point symbols). The displays for this task consisted of three different spatial arrangements of point symbols. Each of these patterns was displayed against the three test backgrounds. The patterns were composed of three raised dots, 3.5 mm in diameter and .84 mm in height. They also varied in their location on the display: pattern 1--top (left of center), middle (right of center), bottom (center); pattern 2--top (right of center), middle (center), bottom (left of center); pattern 3--top (center), middle (left of center), bottom (right of center). Lines composing the grids and axes were the same as those described for Task A.

Task D (determination of coordinate values of a graph point). This task required the construction of three displays. Each contained a raised dot simular to that in Task C, displayed against one of the test backgrounds. In all three cases, the raised dot was located in the upper right quadrant of the display frame, 20.3 cm to the right of and 20.3 cm above the origin, thus maximizing the distances from the dot to the axes. This was done to provide a more stringent assessment of the trackability of the incised grid line. Raised "tick marks" were placed along the axes of all three displays at intervals of 12.7 mm and numbered in braille with positive integers. The numbered progression of the integers was varied between the three displays to control for guessing. All lines were of the same dimensions as those described for Task A.

Procedure and Design

At the beginning of testing the purpose of the study and the nature of the tasks to be performed were explained. Each student was seen individually and all tasks were completed in one session. The four different types of perceptual-motor tasks required of the subjects are described below. Order of presentation was completely counterbalanced, with each subject randomly receiving one of the 24 possible orderings of the four experimental tasks.

Task A. The subject was first familiarized with the line tracking task. The training graphs used for this purpose consisted of a dotted line displayed against the three test backgrounds. The configurations of these line patterns differed from the experimental patterns. The subject was required to trace the dotted line from beginning to end without assistance. Speed and accuracy were emphasized. These displays, as well as all those to follow, were mounted on a clipboard with nonslip rubber backing.

Three line tracking trials immediately followed the training period. The subject's task was to track the dotted line in each of the three background conditions. Order of presentation of the background conditions was completely counterbalanced across subjects.

Each of the three line patterns described previously was present in one of the three test displays. Since six unique sets of three displays can be generated from combining the three line patterns with the three test backgrounds, each set was randomly assigned to four subjects. In other words, all three line patterns appeared an equal number of times in each background condition across subjects. This was done to insure that any potentially biasing effects of line configuration would be equally distributed across experimental conditions.

Duration of tracking and number of path departures were recorded. A path departure occurred if the subject's finger (or lead finger if two fingers were used) lost contact with the line. Knowledge of results was not provided.

Task B. This task involved the location of the highest and lowest excursions of the dotted line. The subject again received familiarization training, beginning with an explanation of the concepts "highest" and "lowest" with respect to the display frame. The subject was then required to locate both the highest and lowest peaks in each of three training graphs involving the raised grid, the incised grid, and the smooth background. The line patterns used in these graphs differed from the experimental patterns. The subject first tracked the line from beginning to end, and then went back and attempted to locate the highest and lowest peaks, indicating their locations with the tap of a finger. Speed and accuracy were stressed.

Three test trials immediately followed familiarization. Order of presentation of the three background conditions was again completely counterbalanced across subjects. As with Task A, six sets of test displays were generated. Each was randomly presented to an equal number of subjects.

The cummulative time needed to sucessfully locate both the highest and lowest points on each of the three displays was recorded. (Note: timing began when the initial tracking of the line was completed). Accuracy of location was quantified in terms of a success/failure dichotomy. If the high or low location was incorrectly identified, the subject was so informed and instructed to continue the search. The number of attempts needed to attain a successful location were tallied.

Task C. This task involved the location of three point symbols contained within the confines of the x and y coordinate axes. The subject was first shown three familiarization displays and told to search the displays for raised dots. Speed and accuracy were again emphasized.

Three test trials immediately followed. Order of presentation of the conditions was counterbalanced, and each of six sets of test displays was again presented to an equal number of subjects. The total time needed to locate the raised dots in each of the three background conditions constituted the data for this task.

Task D. This task involved the determination of the coordinate values of a designated point on the graph. During familiarization the subject was taught to execute the following sequence of task operations: (a) make a vertical movement from the dot to the x-axis (the right index finger was used to make this movement, while the left index finger remained on the raised

dot); (b) report the x value; (c) return the right index finger to the raised dot; (d) make a horizontal movement from the dot to the y-axis (the left index finger was used to make this movement while the right index finger remained on the dot); (e) report the y value. These operations were practiced on graphs involving the three background conditions. The location of the dot differed from that of the experimental displays.

Three test trials then followed, with the order of presentation of the three conditions being completely counterbalanced across subjects. The time needed to complete the entire sequence of operations for each condition was determined. Accuracy was measured in terms of (a) the success or failure in locating the correct values on the x and y axes, and, in the event of a location error, (b) the amount of deviation (in 12.7 mm units) from the correct location.

Results

The means and standard deviations for the performance times in all four tasks appear in Table 1.

Insert Table 1 about here

Task A

As Table 1 illustrates, relative to the control, the raised grid was responsible for a 143% increase in tracking duration. In comparison, the incised grid increased tracking duration by only 25%. An analysis of variance for repeated measures did in fact reveal a significant effect of background condition on line tracking duration, $\underline{F}$ (2,46) = 108.8, $\underline{p} < 0.001$. Post hoc analysis by a Newman-Keuls procedure found significant differences between all conditions ($\underline{p} < 0.01$).

Line departure errors were committed by 87.5% of the subjects in condition R, 29.0% in condition I, and 17.0% in condition C. The average number of errors committed by subjects in condition R was 2.0. None of the subjects committed more than one error in conditions I or C. Differences in number of errors between the three conditions were found to be highly significant by a Friedman two-way analysis of variance (χ^2 [2] = 31.9, $p < 0.001$). A greater number of errors was committed in condition R than in conditions I and C, which did not differ.

Task B

Relative to the control, the data in Table 1 show an 81% increase in location time for condition R and a 21% decrease for condition I. The effect of display background was again significant, F (2,46) = 33.0, $p < 0.001$. Condition R differed from conditions I and C (Newman-Keuls, $p < .01$), while condition I fell just short of differing from condition C ($p < .10$).

Errors in the location of either the high or low peaks were committed by 45.8% of the subjects in condition R, 20.8% in condition I, and 20.8% in condition C. Differences in error rate were significant (Cochran Q Test: Q [2] = 9.0, $p < 0.02$). A greater proportion of subjects committed errors in condition R than in conditions I or C.

Task C

The data in Table 1 show that, for Task C, the raised grid increased location time by 363% relative to the control. In comparison, the incised grid increased location time by only 77%. Differences attributable to type of

background were highly significant, F (2,46) = 34.31, $p < 0.001$. Condition R impaired performance relative to conditions I and C (Newman-Keuls, $p < 0.01$), which did not differ ($p > 0.05$).

Errors were not a factor in the performance of Task C. All subjects were successful in locating the dots in each of the three background conditions.

Task D

The average time required for locating the coordinate values of a designated graph point are shown in Table 1. Differences in the three conditions were significant, F (2,46) = 4.05, $p < 0.025$. Based on a Newman-Keuls post hoc analysis, condition R differed from condition C ($p < 0.05$), but not from condition I.

Both types of grid background facilitated the accurate identification of the coordinate values of a graph point. Only 4.2% of the subjects in condition R and 12.5% of the subjects in condition I committed an identification error, as compared to 91.7% of the subjects in condition C. R and I differed from C (McNemar, $p < 0.01$), but not from each other ($p > 0.05$). None of the subjects who committed errors in R or I were deviant by more than one unit; 54.2% of the subjects committed errors of two or more units in condition C. Moreover, 58.3% of the subjects committed identification errors on both the horizontal and vertical components of the task in condition C. No subject committed errors on both components in conditions R or I.

Subjective Responses

All subjects perceived the qualitative difference between the incised and raised grid lines; subjects typically described the incised line as a "groove," a "line sunk down into the paper," or an "upside-down line." The subjects were unanimous in their opinion that the incised line was easy to track.

Discussion

The results of this study confirmed earlier findings (Barth, 1983) of a detrimental effect of a raised grid on the ability of blind students to track a data curve embedded in it. They also extended these findings by showing that other typical graph reading tasks are similarly affected. Moreover, a change in display design, involving the use of incised tactile elements for the grid background, proved to be a feasible solution to the problem, attenuating the tactile noise while at the same time permitting the precise determination of a graph point's coordinate values.

The use of a raised grid, in comparison to an incised grid, significantly increased the amount of time needed to track a data curve, to locate the highest and lowest excursions of a data curve, and to locate several point symbols. A raised grid was also responsible for an increase in both line tracking departures and errors in locating the highest and lowest excursions of a line. An incised grid, on the other hand, permitted the attainment of performance levels which were generally comparable to those achieved with a smooth, noiseless background (control). Interestingly, there was some indication that, relative to a smooth background, an incised grid is even superior in its facilitation of one task, the location of the minimum and

maximum points of a data curve. It would appear that the incised grid provided a reference system for comparisons between points on the data curve. The height of one point relative to another could be quickly determined from the horizontal grid lines which the fingertip traversed in scanning from one point to the other. This cue was not available in the no grid condition. Although available in the raised grid condition, it was overshadowed by the problem of figure-ground differentiation, which made it more difficult even to locate likely candidates for comparison.

In the only other study involving tangible line graphs, Lederman and Campbell (1982) found that subjects strongly preferred a no grid over a raised grid format for tasks concerned with the configurations of data curves, presumably because the grid made the display more noisy. This subjective evaluation was not, however, supported by speed and accuracy measures of performance. Based on the results of the present experiment, effects of format on performance would be expected, since all of their tasks involved line tracking as one component. It is conceivable that this discrepancy was due either to the use of younger, more inexperienced subjects in the present study and/or the use of more complex data curve configurations than those employed by Lederman and Campbell.

It would have been interesting in both studies to have observed the effects of display format on a secondary loading task. In the Lederman and Campbell study, one might expect that the grid on graph format would precipitate a deterioration in secondary task performance relative to the no grid format, thus providing a rationale for her subjects' strong preference,

despite the lack of performance differences, of a no grid format for questions concerning line configuration. As Kahneman (1973) has pointed out, a given level of efficiency can be attained at different levels of cost or effort.

It should be noted that the subjects in the Lederman and Campbell study did prefer (and their performances were improved by) the grid on graph format for questions concerned with the determination of coordinate values of a point on a data curve. A grid underlay also facilitated such performance, relative to the no grid format. In the present study, an incised grid on graph format was also found to be superior to the no grid format on this type of task. Quality of performance was, however, poorer in Lederman and Campbell's grid on graph condition when the task involved the location and coordinate values determination of data curve intersections. Presumably, the use of raised grid lines in this context created a tactually noisy display, thus impairing performance.

In general, the results of both this study and the Lederman and Campbell study indicate that the standard raised grid on graph format is a rather poor design feature in tangible line graph displays. While Lederman and Campbell eliminated the problem of interfering tactual noise by affixing the grid to the underside of the display (grid underlay), it seems that a more feasible solution lies in the incised grid on graph employed in the present study. This method not only attenuates the tactual noise caused by the presence of the grid, but also eliminates the need to learn the rather complex perceptual-motor skills required by the grid underlay design; that is, the simultaneous coordination and registration of one hand on the front and one hand

on the back of the display. It would seem that a more compatible stimulus-response relationship is realized with the incised grid on graph format. A direct comparison of these two design alternatives should be the subject of a future research effort.

References

Barth, J. L. The development and evaluation of a tactile graphics kit. Journal of Visual Impairment and Blindness, 1982, 76, 269-273.

Barth, J. L. Factors affecting line tracing in tactile graphs. Journal of Special Education, 1983, 17, 215-226.

Bentzen, B. L., & Peck, A. F. Factors affecting traceability of lines for tactile graphics. Journal of Visual Impairment and Blindness, 1979, 73, 264-269.

Berla', E. P. Tactile scanning and memory for a spatial display by blind students. Journal of Special Education, 1981, 15, 341-350.

Berla', E. P., & Butterfield, L. H. Tactual distinctive features analysis: Training blind students in shape recognition and in locating shapes on a map. Journal of Special Education, 1977a, 11, 335-346.

Berla', E. P., & Butterfield, L. H. Tactile political maps: two experimental designs. Journal of Visual Impairment and Blindness, 1977b, 71, 262-264.

Berla', E. P., Butterfield, L. H., & Murr, M. J. Tactile political map reading by blind students: A videomatic behavioral analysis. Journal of Special Education, 1976, 10, 266-276.

Berla', E. P., & Murr, M. J. Psychophysical functions for active tactual discrimination of line width for blind children. Perception & Psychophysics, 1975a, 17, 607-612.

Berla', E. P., & Murr, M. J. The effects of tactual noise on the location of point symbols and tracing a line on a tactile pseudomap. Journal of Special Education, 1975b, 9, 183-190.

Geldard, F. A. The human senses (2nd. ed.). New York: Wiley, 1972.

Gill, J. M. Method for the production of tactual maps and diagrams. American Foundation for the Blind Research Bulletin, 1973, No. 26, 203-204.

James, G. A. Kit for making raised maps. New Beacon, 1975, 59, 85-90.

James, G. A., & Armstrong, J. D. An evaluation of a shopping centre map for the visually handicapped. Journal of Occupational Psychology, 1975, 48, 125-128.

Kahneman, D. Attention and effort. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

Kirchner, C. Non-text reading matter: How should it be presented? Journal of Visual Impairment & Blindness, 1979, 73, 329.

Lederman, S. J., & Campbell, J. I. Tangible graphs for the blind. Human Factors, 1982, 24, 85-100.

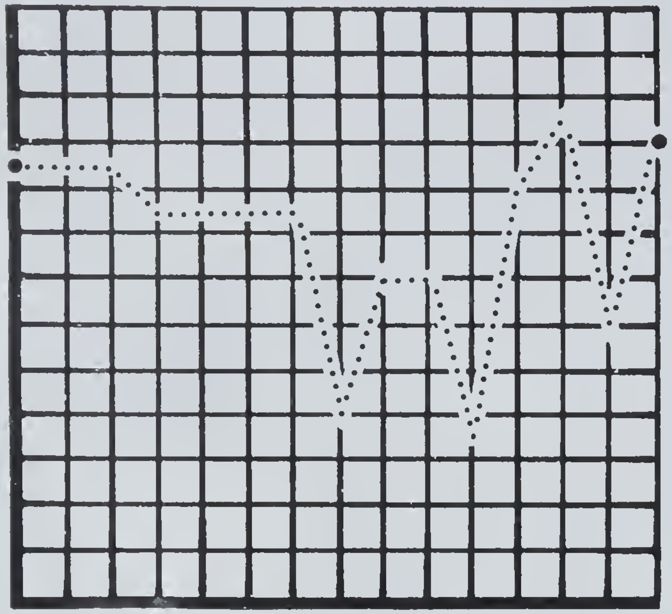
Nolan, C. Y. Relative legibility of raised and incised tactual figures. Education of the Visually Handicapped, 1971, 3, 33-36.

Nolan, C. Y., & Morris, J. E. Improvement of tactual symbols for blind students: Final Report. Louisville, Ky.: American Printing House for the Blind, 1971.

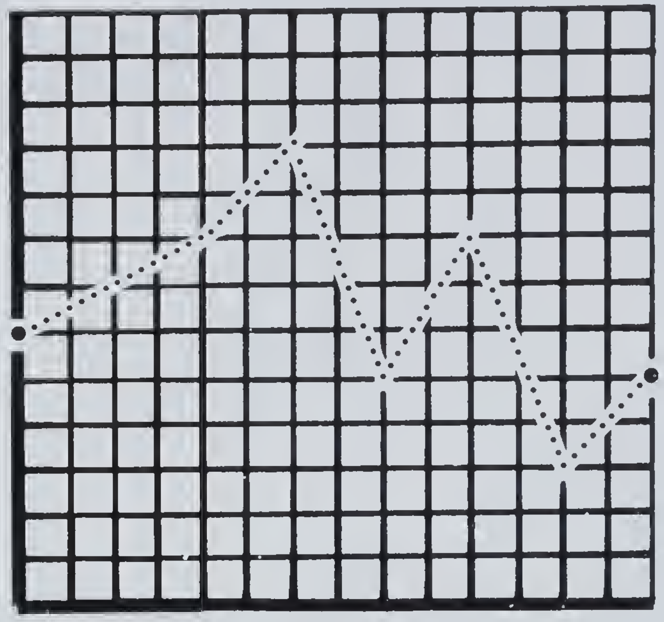
Schiff, W., Kaufer, L., & Mosak, S. Informative tactile stimuli in the perception of direction. Perceptual & Motor Skills, 1966, 23, (Monogr. Supplement 7).

Wiedel, J. W., & Groves, P. A. Tactual mapping: Design, reproduction, reading, and interpretation: Final Report. College Park, Md.: University of Maryland, 1969.

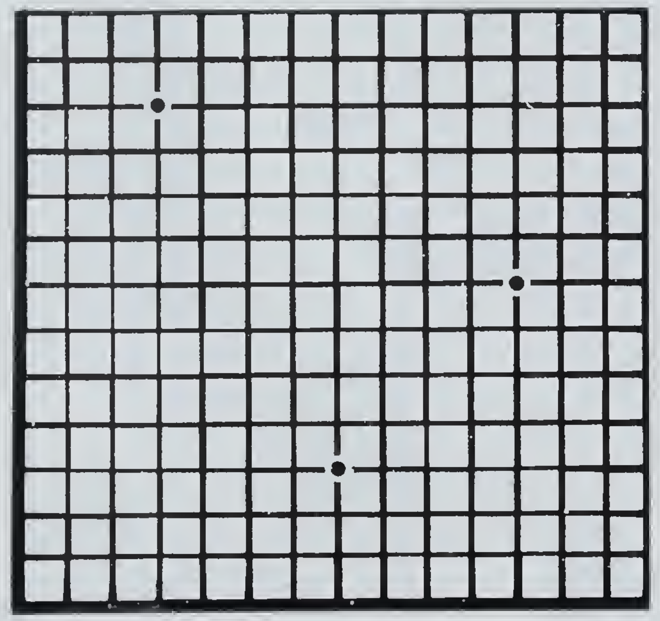
Figure 1. Exemplary displays for the four experimental tasks.



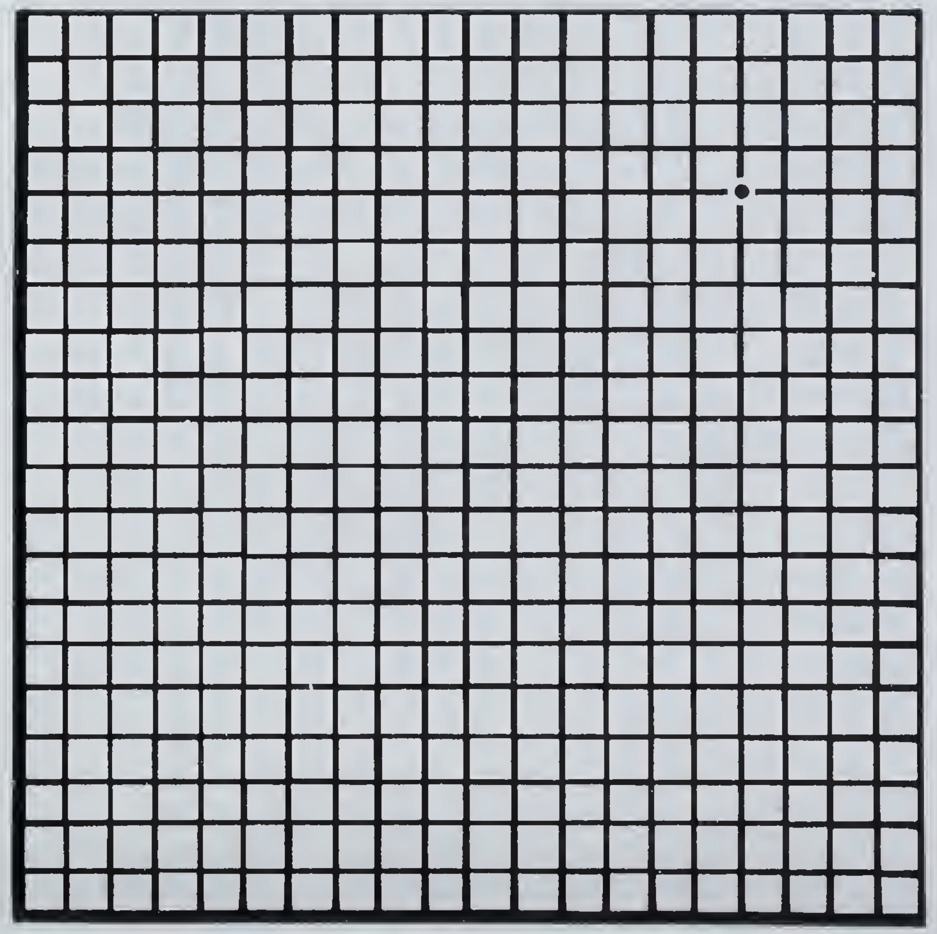
Task A



Task B



Task C



Task D

Table 1

Mean Task Times for the Three Background Conditions

(Standard Deviations in Parentheses)

	Task			
Condition	A	B	C	D
Raised grid	22.4 (7.5)	21.0 (11.1)	25.0 (16.5)	10.8 (3.7)
Incised grid	11.5 (3.8)	9.2 (5.7)	9.7 (9.3)	11.0 (4.2)
No grid	9.2 (2.9)	11.6 (8.4)	5.4 (2.6)	12.8 (5.3)

John L. Barth is a research psychologist in the Department of Educational Research at the American Printing House for the Blind, Louisville, Kentucky. He conducted research in the Performance Research Laboratory and the Perceptual Alternatives Laboratory at the University of Louisville while pursuing his Ph.D. in experimental psychology, which he received from that institution in 1979. He is currently involved in product development, equipment design, training, and display design in the area of tangible graphics. He is a member of the Human Factors Society.